Optical Method for Measuring the Mean Diameter of Glass Wool Fibers

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An optical method for measuring the mean diameter of glass wool fiber is proposed and discussed from the viewpoint of practical use. The method uses both light scattering and light reflection off glass wool. The method can measure mean fiber diameters in the area illuminated by laser light in real time.

Key Words: Glass wool fiber, Mean diameter, Optical measurement

1. Introduction

Processed goods made of glass wool have widely been used as adiabatics and sound-proof materials, particularly in the construction and automotive industries. The quality of such goods depends largely on the weight density and fiber diameter of the glass wool. We have developed a real time densitometer of glass wool using white light as a light source and a solar cell as a light sensitive receiver for industrial use.[1)]

Many methods have been developed for the measurement of glass fiber diameters.[2-4)] These methods, however, can only measure the diameter of each fiber in real time and cannot measure the mean diameter of many fibers. In manufacturing applications, it is usually more important to know the mean diameter.

In this paper, we have developed a simple optical system for measuring the mean fiber diameter of glass wool in real time and demonstrated the validity of the method in practical use.

2. Principle and method

The method of this system is based on the principle of scattering and reflection of the laser light on the glass wool surface. The method therefore measure the mean diameters of the fibers irradiated by the laser light.

Figure 1 shows the sensor head of the system. A semiconductor laser of wavelength 640 nm is used as a light source and two photodiodes as light receivers. One photodiode is used for the reflected light intensity and the other for the scattered light intensity. The rationale for using two receivers will be explained in section 3. All the elements were fixed in a dark box to eliminate noise light, *i.e.*, ambient light.

A laser light window constituting of a glass disk was used to keep away the reflected light on the upper surface of the window from the one on the lower surface as shown in the figure. The glass wool is pressed by the glass window to form a flat surface, *i.e.*, a glass wool plate. The obliquely illuminated laser light is scattered and reflected on both the glass wool plate and the glass window. The signal is a scattered light intensity I_s only on the glass wool plate. The scattered light intensity on the glass plate, I_n, is a noise and thus should be removed. It is, however, impossible to experimentally distinguish these signals and noise lights at the receiver. We therefore measure only the noise light intensity by using a black cloth in place of the glass wool. The true signal light intensity I_s can then be obtained from both the measured intensity I_t and the noise intensity I_n: $I_s = I_t - I_n$. This further enables us to use any kind of glass window. That is, for example, we can use a worn glass plate. The intensities of both reflected and scattered laser lights strongly depend on the optical arrangement, *i.e.*, the position and direction of the laser and the two photodiodes. The semiconductor laser and the photodiode for measuring the reflected light intensity are set obliquely at about 45° from the glass window surface, as shown in Fig.1. Both distances are about 4 cm from the glass window. The photodiode for scattered light is set just above the glass window at a distance of about 2 cm.

Both measured light intensities are amplified, digitized by a 12 bit A/D converter, calculated by a personal computer, and displayed. These measurement can be made in an instant, which is one of the greatest merits of the microscopic method usually used.

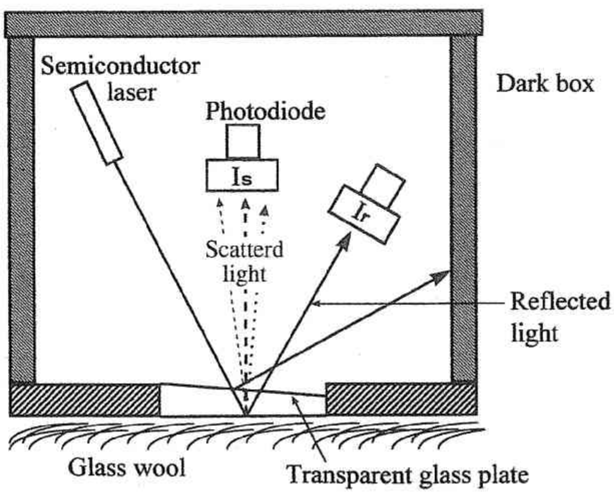

Fig.1 Sensor head of the system.

3. Experimental results and discussion

To verify the validity of this method, we performed an experiment using two kinds of glass fibers, A and B. The mean diameter of type A fibers ranged from 1.5 ~ 2.5 μm, and that of type B fibers from 4.0 ~ 7.0 μm.

Figure 2 shows both the scattered and reflected light intensities and ratios of the two kinds of fibers. Both intensities shows the true signal components. Each value represents the mean of 10 measurements. The fluctuation of each measured value was about 10%. The reflected light intensity I_r increased nearly in proportion to the increase of the fiber diameter d for both kinds of glass fibers. In contrast, the scattered light intensity I_s changed in inverse proportion to d. This result can be explained by Fig.3. As can be seen, in the case of small fiber diameter, more scattering fibers are included in the same irradiated region and the scattering intensity is increased. On the other hand, the reflected light intensity decreases because the light reflecting surface, that is, the mirror region, in each fiber decreases with decreasing diameter of the fibers.

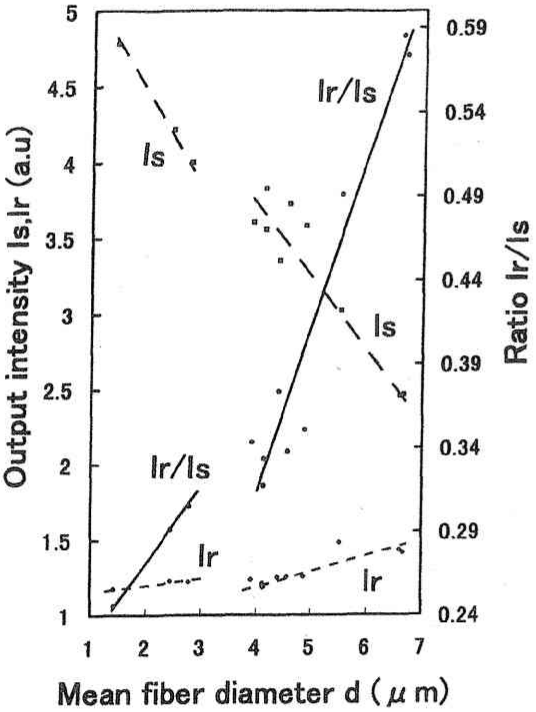

Fig.2 Reflected and scattered light intensities and the ratio of these intensities to the glass wool diameter. Each value of light intensity is an average of ten measurements and the value of the fiber diameter is the average of about 500 samples.

Each light intensity thus provides the needed information on the fiber diameter. However, we use the ratio I_r/I_s for the estimation of fiber from the viewpoint of sensitivity S. The sensitivity of this method is defined by a small increment of the light intensity ΔI to a small increment of Δd:

$$S = \Delta I / \Delta d$$

Both the reflected and scattered light intensities depend on the fiber diameter d as shown in Fig.2. The sensitivity is defined for both light intensities: $S_r = \Delta I_r / \Delta d$ for reflected light, and $S_s = \Delta I_s / \Delta d$ and $S = (\Delta I_r / \Delta I_s)$ for the ratio between the intensities. Both light intensities are roughly expressed as $I_r = K_r d^a$ and $I_s = K_s d^{-b}$ in Fig.2, where K_r and K_s are constant and a and b are positive real numbers. The magnitude between these sensitivities has, then, the relation $|S_r|,\ |S_s| < |S|$. That is, the sensitivity based on the intensity ratio is larger than the others, and for this reason two light receivers are used. The reflected light intensity has also been used to monitor the reflexibility of the glass wool, and particularly in regard to the color, since the reflexibility has almost the same influence on both the reflected and the scattered light intensities.

Figure 4 shows a representative example of a direct microscopic measurement of fiber diameter. The diameter extends over a wide range. This is true for all the practical manufactured goods used as samples in this experiment. It is thus indispensable to conduct numerous measurements of the light intensity, as discussed in our previous paper.[5] The data in Fig.2 represent the average of 10 measurement for the light intensity and the arithmetic average of 10 measurements for the diameter. Thus, the accuracy of this method cannot be discussed due to the wide distribution of fiber diameters. However, we can conclude that the method will successfully determined a rough estimation of the mean diameter in real time.

4. Conclusion

An optical method for estimating glass wool fiber diameter has been proposed and discussed from the viewpoint of industrial use. The method has the following features:

(1) It can measure the mean value of the fiber diameter in an irradiated area.

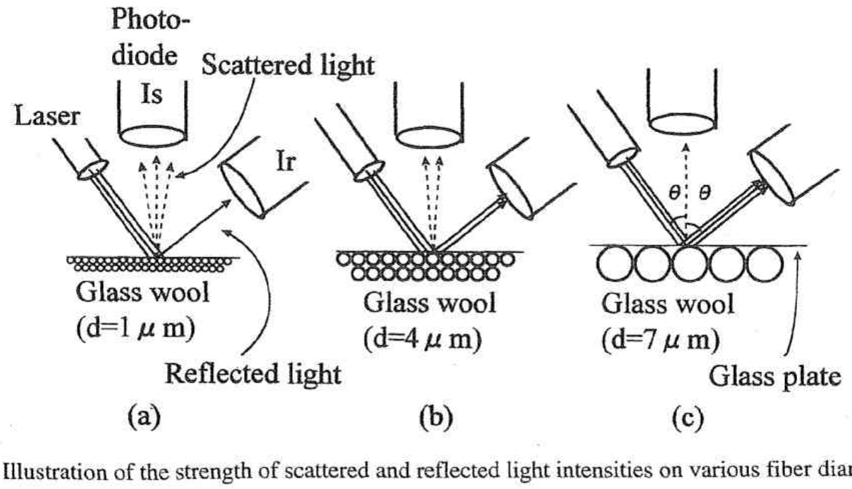

Fig.3 Illustration of the strength of scattered and reflected light intensities on various fiber diameters.

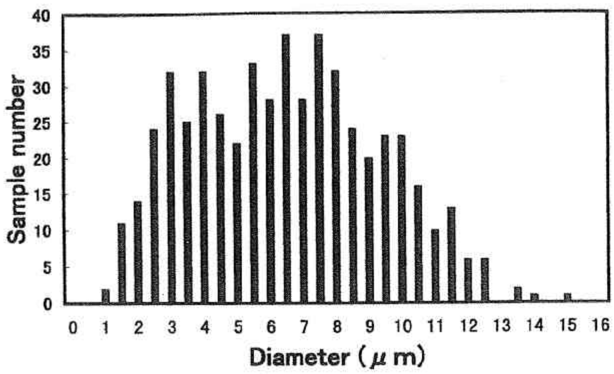

Fig.4 Actual fiber diameters measured microscopically. Sample number, 542; maximum diameter, 15.1 μm; minimum diameter, 0.76 μm; diameter range, 14.4 μm; standard deviation, 2.93; standard error 0.13; averaged diameter, 6.61 μm.

(2) It can measure the fiber diameter in real time.
(3) It is very simple to construct and to use.

Acknowledgement

We express our appreciation to Mr. Toshiaki Tanaka of Japan Inorganic Chemistry Co., Ltd. for his useful discussions and technical support in preparing the numerous types of glass wool. We also thank Mr. Toshio Inaki of Fukui University.

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